EFFECT OF FLY ASHES ON THE RHEOLOGICAL PROPERTIES OF FRESH CEMENT MORTARS

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ABSTRACT

Concrete and the transport of the fresh concrete by pumping is an important construction material and widely used in the actual concrete technology. This process has been applied since the beginning of the twentieth century. Developments of the pumping equipment and new findings in mineral and chemical admixtures (superplasticizer) in last decades obliged the concrete technologists to undertake more sophisticated researches on pumping concretes. Pumping concretes are fluid but also have sufficient cohesion provided by fine particles as stone powder or fly ashes. It is obvious that fly ash is preferred because its use also improves the impermeability to water and ions due to its pozzolanic activity. The consistency and workability of fresh cement mortar and concrete are two important properties of fresh concrete that must be identified on a job site regardless of the sophistications required for obtaining a suitable mix. Consistency and workability are a simple index of mobility, flowability, finishability, compaction, and placeability. They affect the appearance and the over all cost of the finished concrete. In the construction field terms like workability, flowability and cohesion are used to describe the behaviour of concrete under flow. The definitions of these terms are very subjective. Therefore, there is a need for a more fundamental and quantitative description of concrete flow. Rheological measurements of concentrated suspension can be used to describe the flow of concrete. The rheological constants (yield value and plastic viscosity) of the mortar can be determined with a co-axial viscosimeter, and this process is applied in this study. If the efficiencies of the mortar phase on the cohesion, fluidity, bleeding and the friction with the pipe of the concrete are taken into consideration this approach can be admitted beneficial and helpful. Rheological tests on mortars were carried on with a Mettler RM 180 Rheomat co-axial viscosimeter. The angular deformation rate ($\dot{\gamma}$) and shearing stresses (τ) were computed, and the $\dot{\gamma}$-τ diagrams were drawn. All the mortars showed a tixotropic behaviour conformable to Binghamien model. The linear regression on the linear parts of these graphics gave the yield value (τ_o) and the plastic viscosity (η_{pl}) of the mortars.

KEY WORDS : Binghamien model; co-axial viscosimeter; fly ash; plastic viscosity; pumping concrete; superplasticizer; workability; yield value.

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1. INTRODUCTION

Concrete is an important construction material and the transport of the fresh concrete by pumping is an important process and widely used in the actual concrete technology. This process has been applied since the beginning of the twentieth century. Developments of the pumping equipment and new findings in mineral and chemical admixtures in last decades obliged the concrete technologists to undertake more sophisticated researches on pumping concretes, concrete types and production methods [1, 2].

It is obvious that pumping concretes in solid state should have sufficient mechanical strength and good durability as the normal concretes. They differ from them only in the fresh state and this difference affects certainly their mix composition and procedure. Fresh concrete has to be produced according to international standards and structural requirements. There are many recommendations for the composition of the pumping concretes. They are not elaborated upon standard specifications, but are very useful in the applications. Besides, in this research, the recommendations of the American Concrete Institute ACI-304.2R are used to determine the gradation of the aggregates and the mix proportions, volume and kind of the aggregates, the absolute volume of the mortar phase [3, 4, 5]. Because of these reasons, we have to learn and develop fresh mortar and concrete properties & test methods. Workability is the most important property of the fresh concrete. Workability is actually determined by standard workability tests such as slump test, K-slump test, Flow Table, Kajima Box, Box Test, J-Ring, L-box, Compacting Factor, Workability Meter, Plasticity Meter. Not all of the standard test Methods are applicable to all consistency levels of fresh concrete. Some of the above mentioned test methods are applicable to dry consistency level; others are valid for plastic & flowable consistency levels [6,7].

All test equipment can be used for different consistency levels and these test results are taken at only single point. The workability of the fresh concrete have complex properties. We may mention these complex properties as following: the cohesion of the concrete should be high to avoid the segregation, but the concrete should be also a flowing one to prevent head loss along the pipe, the bleeding of the concrete should have an optimum value, too little bleeding increases the friction between concrete and pipe, too large bleeding causes blockage of the pipe [8, 9, 10]. So, we have to use more different test methods than those above mentioned fresh concrete tests that are in adequate. It is evident that those tests can not give sufficient information about these specific complex properties. We have to search more types of tests that can give more information about concrete [2, 9,11,12].

2. RHEOLOGICAL PROPERTIES OF MORTAR PHASE

In the construction field, terms like workability, flowability and cohesion are used, some times interchangeably, to describe the behaviour of concrete under flow. The definitions of these terms are very subjective. Therefore, there is a need for more fundamental and quantitative description of concrete flow. Rheological measurements of concentrated suspensions can be used to describe the flow of concrete. Numerous researchers have successfully used the Bingham equation. Two parameters define the flow: yield stress and plastic viscosity. Yield stress is related to slump, but plastic viscosity may be related to properties such as stickiness, placeability, pumpability, and finishability. In addition, segregation could be defined as the ability of the aggregate to migrate in the cement paste. This phenomenon is linked to the viscosity of the cement paste and the concrete mix design. Therefore, methods to predict concrete workability need to be taking into account more than just the yield stress [7, 13].

The “two point workability test apparatus” which helps to obtain the yield value and the plastic viscosity of the concrete may give more detailed and necessary information for the workability of the pumping concrete. Also, the rheology of fresh mortar is important in understanding of the behaviour of fresh concrete and predicting the flow properties of fresh concrete. In this work, the effects of mixing procedure, testing procedure and relative proportions of constituent materials on the rheology of fresh mortar as measured by the co-axial viscosimeter have been studied. The rheological constants (yield value and plastic viscosity) of the mortar can be determined with a co-axial viscosimeter, and this process is applied in this study. If the efficiencies of the mortar phase on the cohesion, fluidity, bleeding and the friction with the pipe of the concrete are taken into consideration, this approach can be admitted beneficial and helpful [4, 11, 12, 14, 15].

3. STATE OF THE CONCRETE IN FLOW

In addition, another important subject is the theoretical investigation of the hydrodynamic behaviour of the pumping concrete in pipe. This behaviour is very difficult, even impossible. The concrete mass, which is gaining velocity under pressure gradient and translating, is a viscous suspension containing coarse and non uniform size in solid particles. The motion of this suspension in the pipe should be uniform and laminar without exceeding the limit of turbulence, this is necessary for preventing the segregation. On the other hand, the transport must be achieved with low pressure and energy. The factor increasing the pressure and energy is the friction between concrete and pipe wall, if the pressure of the pump is increased to overcome this friction another danger may appear; attaining the limit of segregation pressure, the mortar can separate from the mass and the aggregate particles block the pipe [5, 12, 16- 18].

The role of the mortar in all these phenomena is primordial. The gradation and the fineness of the sand, cement and admixtures content and the water/cementitious material ratio of the mortar are the composition parameters of the mortar, which affect the behaviour of the concrete in the pipe. The mortar can provide cohesion of the concrete, but should be fluid enough for seeping through the concrete and forming a gliding layer on pipe wall. The combined use of a superplasticizer and fly ash is an optimum solution for pumping requirements of concrete. Admixtures mainly affect the flow behaviour of the cement paste of concrete [2, 12, 20-22].

4. EFFECTS OF ADDITIVES ON WORKABILITY AND STRENGHT

The mortar can provide cohesion of the concrete, but should be fluid enough for seeping through the concrete and forming a gliding layer on pipe wall. The mortar possessing these properties has a low yield value and moderately high plastic viscosity. The cohesion of the mortar may be increased by adding some fine mineral additive such as fly ash and the fluidity may be improved by adding a plasticizer or superplasticizer. It is supposed that the plasticizers decrease the yield value without diminishing significantly the plastic viscosity. Therefore the combined use of a superplasticizer and fly ash is an optimum solution. This method is applied in this work [19-21, 23].

It is usually reported that, if the volume concentration of a solid is held constant, the addition of mineral admixtures improves concrete performance but reduces workability. The most common reason for poor workability is that the addition of a fine powder will increase the water demand due to the increase in surface area. This problem can be solved by using chemical admixtures. However, in certain cases, it is reported in the literature that the use of fine material admixtures can reduce the water demand or increase the slump. A popular hypothesis put forward to explain the workability enhancement due to the use of certain fine mineral admixtures, especially fly ash (FA) or Silica fume (SF), is that the spherical particles easily roll over one another, reducing interparticle friction [6, 7, 13].

The use of fly ash in concrete technology obtained an important place in recent years. The increase of the number of power plants working with coal or lignite in the world began to cause ecological pollution problems due to the by production of fly ash. This pozzolanic material is no more admitted as a dangerous waste material, but a necessary mineral additive for manufacturing an economic, durable and workable concrete. Countless researches are carried on fly ash concretes. Fly ashes of Lignites are classified as C Class fly ash in ASTM. They contain more CaO than F class fly ashes contain; the latter ones are rich on SiO_2 and Al_2O_3 contents, giving them higher pozzolanic activity. Turkey has many beds of lignite and uses them in its power plants. For this reason, the majority of Turkish fly ashes are C class fly ash, another type of fly ash is sulfo–calcic fly ash, which also contains $CaSO_4$; it is not cited in ASTM Specification. The high content of free lime and sulfate in C and especially in sulfo-calcic fly ash may disturb the durability of the concrete. But positive progress was obtained to improve their quality and to use them successfully in dam constructions. [25-30].

The use of fly ash in ready mixed concrete is necessary, even compulsory for obtaining a pumpable, durable and economic concrete. Pumped concrete have two essential properties: fluidity and cohesion. Cohesion which provides the stability of the mix prevents the segregation of coarse aggregates in pipes and it is obtained by adding fine particles and/or increasing the quantity of the sand and cement. Fly ash particles finer than cement particles improve the gradation without impairing the fluidity due to their spherical form. Fly ash addition also improves the impermeability of the concrete to water and chloride ions. The chloride diffusion is the main cause of the embedded steel corrosion in reinforced concretes; the chloride ions suppress the beneficial effect of alkaline passivation due to the presence of $Ca(OH)_2$ of the hydrated cement. Minimum cement content is also needed for obtaining the pozzolanic efficiency of the fly ash. Replacement of the cement by fly ash decreases the compressive strength of the concrete. To compensate this loss, the absolute volume of the fly ash should exceed the replaced cement volume, i.e. the total quantity of the binder (cement+fly ash) will be greater than the initial cement content. The problem is determination of the fly ash quantity for obtaining the compressive strength required. This estimation is possible if the binding capacity of the fly ash in comparison to that cement is known. The ratio of binding capacity of the fly ash to that of cement is called “efficiency factor” (E). In previous studies, the values of the efficiency factor for different Turkish C class fly ashes have been determined. Size properties and efficiencies for Turkish C class fly ashes are shown in Table 1. Oxide and physical compositions of fly ash and PC 42.5 are shown in Table 2 [4, 8, 10, 12, 31].

Table 1. Size properties and efficiencies of fly ashes.

	FA1 Orhaneli	FA2 Cayirhan	FA3 Seyit Ömer
10µm - 40µm fraction (%)	42.6	28.3	43.9
D_{median} (µm)	29	33	23
Blaine Fineness Modulus (m^2/kg)	303	350	402
Specific gravity (kg/m^3)	2.400	2.300	2.100
Efficiency factor, E (for C= 350 kg/m^3)	0.43	0.37	0.61

Table 2. Oxide and physical compositions for fly ash and PC 42.5.

Oxide parameters	%, mass			
	FA1 Orhaneli	FA2 Cayirhan	FA3 Seyit Ömer	PC 42.5
SiO_2	34.8	43.4	46.7	23.0
CaO	26.3	14.2	12.4	63.3
MgO	1.7	4.6	4.6	0.9
Fe_2O_3	3.9	8.4	9.8	4.0
Al_2O_3	19.4	14.2	16.8	4.5
Na_2O	2.7	4.4	2.8	-
K_2O	1.9	2.2	2.7	0.5
SO_3	6.3	5.8	2.9	2.3

5. EXPERIMENTAL

In the construction field, terms like workability, flowability and cohesion are used to describe the behavior of pumping concrete under flow through the pipe. The definitions of these terms are very subjective. We remember that pumping concrete differs from conventional concrete only in its level of workability. In this study, the pumpability of the concretes manufactured with mortars having different rheological constants is investigated. We may give a clear, short and concise definition to the pumpability.
Rheological tests on mortars were carried on with a Mettler RM 180 Rheomat co-axial viscosimeter (See Figure 1).
The mortars were placed in viscosimeter tube following 8, 18 and 28 minutes from the beginning of their mixing with water. A program of 8 steps was performed, and the rotation rates and torques were measured in each step Basing these figures, the angular deformation rate ($\dot{\gamma}$) and shearing stresses (τ) were computed, and the $\dot{\gamma}$-τ diagrams

were drawn. All the mortars showed tixotropic behaviour conformable to Binghamien model. The Rheological behaviour of a fluid such as cement paste, mortar or concrete is most often characterized by at least two parameters, the yield value (τ_o) and the plastic viscosity (η_{pl}) as defined by the Bingham Equation (1). The linear regression on the linear parts of these graphics gave the yield value and the plastic viscosity of the mortars [2, 6-7, 13, 32-35].

$$\tau = \tau_o + \eta_{pl}\ \dot{\gamma} \qquad (1)$$

All the measured flow curves could be very well described by the given formula. Some examples are shown in Figure 2. The sand, cement and fly ash were first mixed in dry state and then during 2 minutes, these were mixed with water by an 800 rpm mixer. The superplasticizers were added after 2 minutes and the mortar was mixed for 5 minutes.

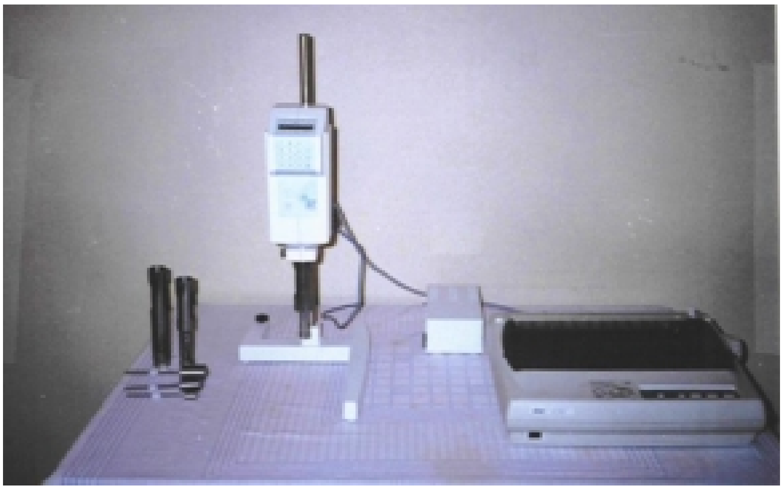
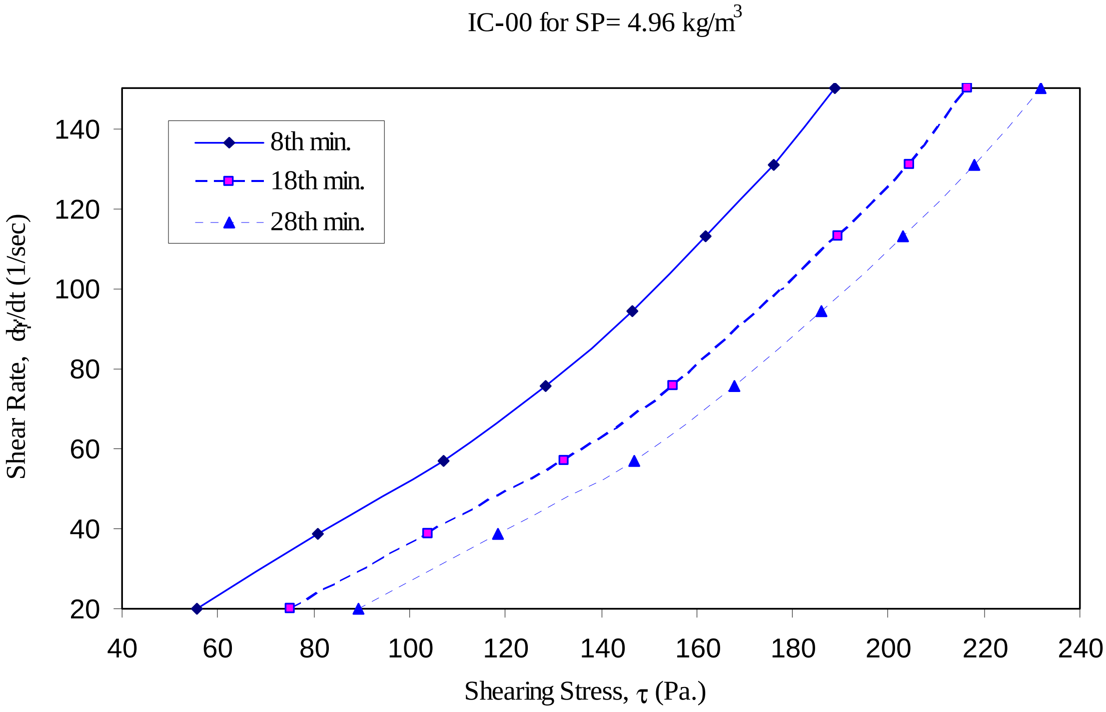


Figure 1. Mettler RM 180 Rheomat (Co-axial viscosimeter).

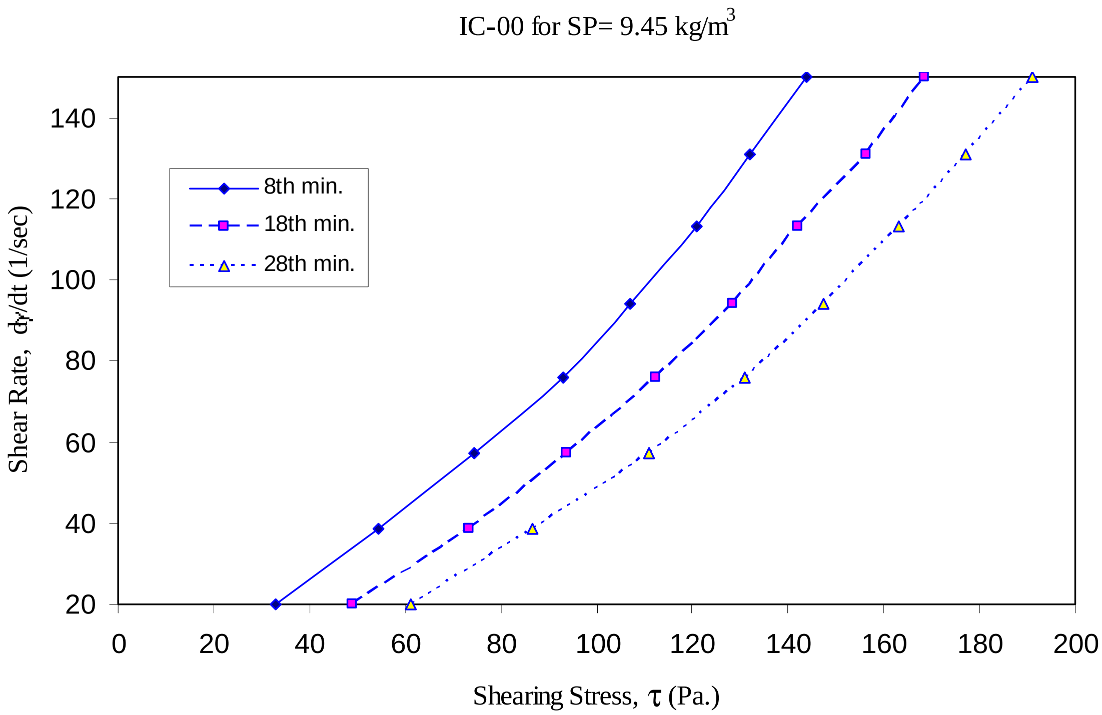
Some principles were proposed and applied on the choice of materials and the computation of ingredients:

- The natural stock of the ASTM-F type fly ash is limited in Turkey; using ASTM-C class fly ash in the research would be more realistic for the Turkish concrete industry. To realize this aim, three kinds of fly ashes were examined from the point of view of water and superplasticizer requirements to obtain high strength concretes prerequisite, the most convenient was used in the main research. Test results of Orhaneli fly ash are more realistic than the other fly ashes. All applied mortar rheological tests are presented in this work [25, 26, 36].
- The fly ash content must be determined by applying the partial replacement method. Thus a preliminary investigation was undertaken to find out the efficiency factors of the fly-ashes and these factors were used to estimate the quantity of fly ash content. The ACI - 304.2R recommendations are applied for the aggregate gradation and mix design. Therefore the aggregate absolute volume is taken as 0.55 m^3/m^3. In that case the volume of the mortar phase was approximately 0.45 m^3/m^3 in all the series. The maximum size of the sand was 2.38 mm. [25, 26, 31].

PC-42.5 Portland cement corresponding to ASTM type III cement and naphthalene sulfanate formaldehyde condensate superplasticizer were used. Oxide compositions of PC-42.5 Portland cement is shown in Table 3.

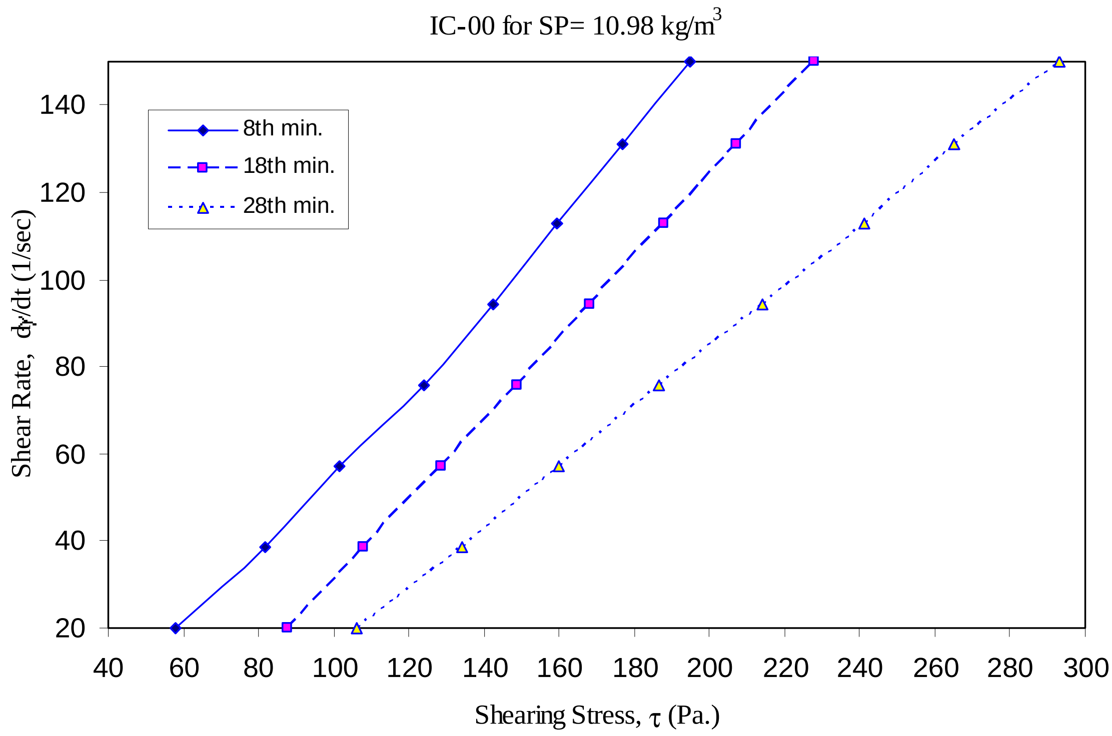


(a)



(b)

Figure 2. Flow curves for mortar phase obtained in Mettler RM 180 Rheomat



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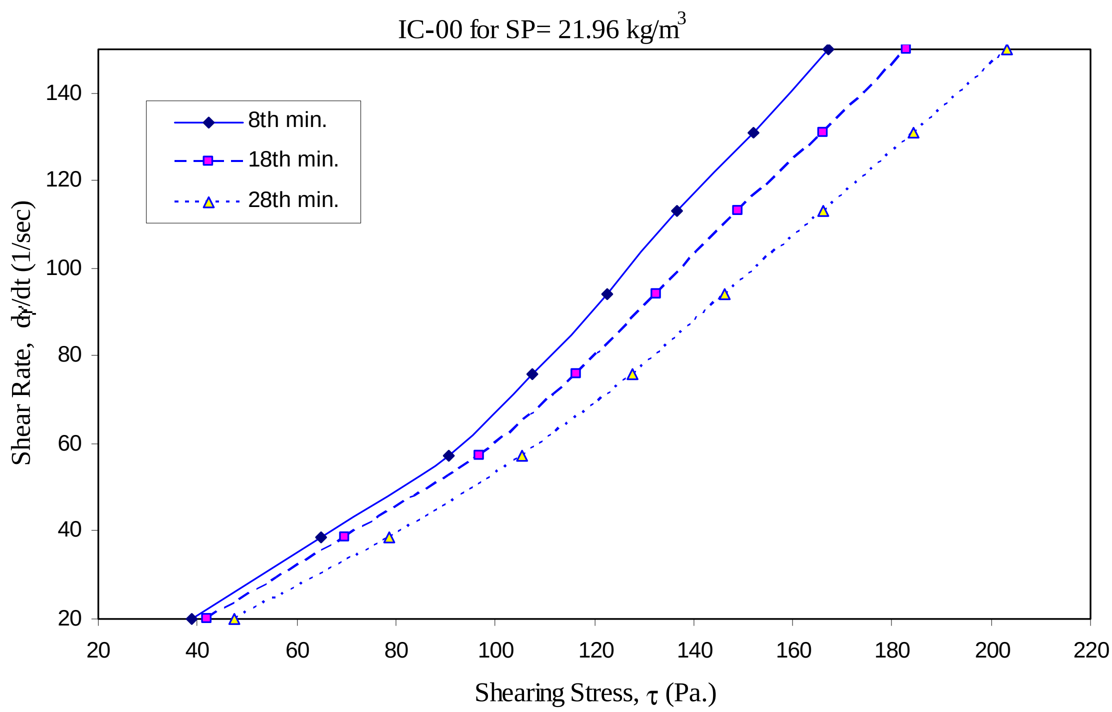

(d)

Figure 2. Flow curves for mortar phase obtained in Mettler RM 180 Rheomat (Continuing)

Table 3. Oxide compositions of Cement.

	PC 42.5 (%, mass)
C_3S	51.7
C_2S	22.8
C_3A	8.6
C_4AF	9.4
SO_3	2.7
Fineness Modulus (m^2/kg)	347

Based on the preliminary test results on the fly ashes, the most suitable one, Orhaneli fly ash was found. Seyit Ömer fly ash was too fine (Blaine 402 m^2/kg) and Cayirhan fly ash contained less particles between 10 and 40 μm size (28.3 %). Seyit Omer fly ash required high quantity of water and superplasticizer. The main principle in tests was to keep the volume of the mortar phase and to change its quality. This change was realized by choosing two different initial cement content, replacing cement by different amount of fly ash and adjusting the superplasticizer addition with different quantity. The initial cement contents in calculation works were fixed as 300 kg/m^3 and 400 kg/m^3. The water contents were kept constant, but the superplasticizer additions increased significantly.

It will be more convenient to summarize the conclusions of this research in three different rubrics: modifications occurred in the rheological behaviour of the mortar phase and the influences of the rheological constants of the mortar on the concrete pumpabilities.

As mentioned above for a good pumpability, the yield value (τ_0) should have a low value and the plastic viscosity (η_{pl}) should not decrease too much. The superplasticizer addition of to the mortar, decrease in τ_0 was 78% and that in η_{pl} was only 35%. This result is in conformity with the aim proposed. The addition of a fly ash to a super plasticized mortar increased the values of τ_0 and η_{pl} in the same manner, but this increase is not too significant. It is interesting to note that this increase is continuous in τ_0 for all the fly ash addition ratio, but if the addition of the of the fly ash exceeds 40-50% of the cement content (15-25% in partial replacement) η_{pl} begins to decrease. According to experimental results and economic necessity it can be suggested that the selection of the superplasticizer/cementitious material ratio between 2 and 2.5 % (as a solid material), cement content 400 kg/m^3 , addition fly ash between 25-35% may give the best result. In that case τ_0 has a value between 38 and 48 Pa, and η_{pl} between 0.8-1.0 Pa.sec. Rheological constants appear in Table 4, Table 5 and Table 6 for each of the mortar mix. The addition of a superplasticizer to the mortar mixes increased the consistencies as expected beforehand. If higher initial cement content is chosen and a quantity of fly ash less than 15 % replaces partially the cement, the solution is sufficiently economic.It was possible to establish linear relation between the cohesion of the concrete and the rheological constants of the mortar phase. In general the increases of the τ_0 and η_{pl} values induce the increase of the concrete cohesiveness.

Table 4. Components, Rates and Rheological Constants of Mortar Phases with Orhaneli Fly Ash.

Code	C	FA	C/(FA+C)	FA/(FA+C)	W/(FA+C)	SP/(FA+C)	τ_o (Pa)			η_{pl} (Pa. sec)		
	kg/m^3						8th	18th	28th	8th	18th	28th
							min.					
IC - 00	738	0	1	0	0.376 0.377 0.380	0.007 0.008 0.013	68.8 63.2 42.1	95.7 81.1 56.4	104.0 92.9 70.9	0.812 0.729 0.685	0.820 0.810 0.755	0.863 0.826 0.807
IC - 15	599	259	0.70	0.30	0.309 0.313 0.316	0.013 0.019 0.026	52.2 46.8 45.9	67.9 56.6 47.9	78.5 60.5 47.8	0.952 0.842 0.814	1.064 0.957 0.900	1.635 1.209 1.036
IC - 25	497	516	0.49	0.51	0.264 0.267 0.271	0.032 0.038 0.045	83.0 76.3 72.8	86.6 80.3 78.6	94.5 81.8 79.8	0.766 0.675 0.657	0.928 0.877 0.831	1.058 0.988 0.974
IC - 35	390	866	0.31	0.69	0.232 0.244	0.090 0.110	118.3 113.8	137.7 116.3	127.8 117.0	0.534 0.527	0.588 0.539	0.604 0.536
IIC - 00	606	0	1	0	0.380 0.387 0.394	0.038 0.051 0.064	56.5 54.3 51.4	60.9 56.7 54.3	64.1 59.1 56.0	0.639 0.513 0.473	0.662 0.575 0.529	0.707 0.621 0.602
IIC - 15	475	357	0.57	0.43	0.271 0.279 0.284	0.050 0.064 0.074	36.3 35.8 34.7	46.8 45.6 44.4	53.0 48.9 45.6	0.928 0.799 0.783	0.955 0.868 0.822	1.085 0.939 0.842
IIC - 25	384	694	0.36	0.64	0.214 0.225	0.074 0.093	50.4 46.6	54.1 50.2	56.4 51.9	0.621 0.547	0.690 0.593	0.739 0.669

Table 5. Components, Rates and Rheological Constants of Mortar Phases with Cayirhan Fly Ash.

Code	C	FA	$\frac{C}{FA+C}$	$\frac{FA}{FA+C}$	$\frac{W}{FA+C}$	$\frac{SP}{FA+C}$	τ_o (Pa)			η_{pl} (Pa. sec)		
	kg/m^3						8th	18th	28th	8th	18th	28th
							min.					
IC - 00	738	-	1	0	0.376 0.377 0.380	0.007 0.008 0.013	68.8 63.2 42.1	95.7 81.1 56.4	104.0 92.9 70.9	0.812 0.729 0.685	0.820 0.810 0.755	0.863 0.826 0.807
IC - 15	590	293	0.67	0.33	0.301 0.304 0.308	0.013 0.019 0.026	46.5 40.5 33.4	58.1 45.4 42.1	73.4 59.5 39.2	0.592 0.503 0.448	0.694 0.650 0.527	1.082 0.855 0.635
IC - 25	487	560	0.47	0.53	0.250 0.255 0.259	0.032 0.038 0.045	75.3 66.2 58.6	82.0 71.2 66.3	85.2 79.8 69.3	0.502 0.437 0.381	0.616 0.596 0.590	0.751 0.708 0.690
IC - 35	383	887	0.30	0.70	0.227 0.239	0.090 0.111	95.5 91.3	112.9 99.5	120.0 115.2	0.417 0.342	0.468 0.418	0.543 0.493
IIC - 00	606	-	1	0	0.380 0.387 0.394	0.038 0.051 0.064	56.5 54.3 51.4	60.9 56.7 54.3	64.1 59.1 56.0	0.639 0.513 0.473	0.662 0.575 0.529	0.707 0.621 0.602
IIC - 15	471	369	0.56	0.44	0.267 0.275 0.281	0.050 0.064 0.074	34.6 34.4 31.3	40.1 43.4 43.3	47.4 46.5 42.9	0.519 0.428 0.425	0.561 0.489 0.476	0.650 0.559 0.517
IIC - 25	380	688	0.36	0.64	0.214 0.225	0.074 0.093	47.9 44.6	51.9 49.0	56.1 54.0	0.375 0.310	0.392 0.346	0.418 0.382

Table 6. Components, Rates and Rheological Constants of Mortar Phases with Seyit Omer Fly Ash.

Code	C (kg/m³)	FA (kg/m³)	$\frac{C}{FA+C}$	$\frac{FA}{FA+C}$	$\frac{W}{FA+C}$	$\frac{SP}{FA+C}$	τ_o (Pa)			η_{pl} (Pa. sec)		
							8th min.	18th min.	28th min.	8th min.	18th min.	28th min.
IC - 00	738	-	1	0	0.376 0.377 0.380	0.007 0.008 0.013	68.8 63.2 42.1	95.7 81.1 56.4	104.0 92.9 70.9	0.812 0.729 0.685	0.820 0.810 0.755	0.863 0.826 0.807
IC - 15	607	182	0.77	0.23	0.345 0.348 0.352	0.013 0.019 0.026	93.9 75.9 63.4	113.7 88.9 85.2	141.4 120.2 89.0	1.334 1.236 1.128	1.459 1.387 1.154	1.771 1.711 1.325
IC - 25	514	352	0.59	0.41	0.315 0.318 0.322	0.032 0.038 0.045	144.3 119.4 115.5	154.4 131.8 137.9	176.9 167.4 142.9	1.176 1.165 0.886	1.355 1.399 1.208	1.554 1.474 1.451
IC - 35	418	576	0.42	0.58	0.294 0.306	0.090 0.111	182.7 177.3	213.2 193.6	238.7 228.2	0.994 0.896	1.220 1.182	1.348 1.284
IIC - 00	606	-	1	0	0.380 0.387 0.394	0.038 0.051 0.064	56.5 54.3 51.4	60.9 56.7 54.3	64.1 59.1 56.0	0.639 0.513 0.473	0.662 0.575 0.529	0.707 0.621 0.602
IIC - 15	489	226	0.68	0.32	0.318 0.326 0.332	0.050 0.064 0.074	74.7 73.2 70.3	92.6 91.7 89.1	115.2 106.1 93.4	1.138 1.032 0.983	1.377 1.241 1.214	1.463 1.423 1.419
IIC - 25	404	434	0.48	0.52	0.276 0.287	0.074 0.093	106.6 99.1	115.1 111.9	117.8 119.4	0.967 0.945	0.994 0.875	1.246 1.058

In the case of lean concretes containing a high proportion of fly ash the rate of cohesion increase with τ_0 is significantly high [17,18, 31].

6. CONCLUSION

Investigations have been made on methods of measuring viscosities of fresh mortar, pipe flow of mortar as a fundamental study for rationalization of fresh concrete behaviour. The rheological constants of mortar and concrete of relatively wet consistency can be measured fairly satisfactorily with the double-cylinder rotation viscometer (co-axial viscometer). The flow curves of the mortar conform to the Bingham Model. The effects of different relative proportions of constituent materials and the presence of admixtures and fly ash on the yield value and plastic viscosity are similar to those observed with fresh concrete. This suggests that tests on mortars in the RM 180 Rheomat co-axial viscosimeter might be useful in predicting the behaviour of fresh concrete. Experiments to show the correlations between mortars and concretes would of course be needed to confirm this. The RM 180 Rheomat co-axial viscosimeter is certainly capable of measuring the rheological parameters of mortar, paste and fine grained materials. Mortar and concrete workability can be characterized in terms of the rheological parameters in the Bingham equation. The flow of granular material such as mortar and concrete needs to be defined by at least two parameters, for instance, yield value and plastic viscosity, as defined by the Bingham equation [9,11-13, 31].
As a final conclusion one may pretend that the determination and improvement of the rheological constants of the mortar phase are necessary and sufficient for obtaining a pumpable concrete. In regard of economy, strength and durability, the most convenient solution to obtain a good pumpable concrete is to keep the nominal cement content at the level of 400 kg/m^3, to replace 15-20% of this cement content by fly ash and to add sufficient quantity of superplasticizer for the fluidity required [17, 18, 31, 36, 37].

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Notations

C	:	Cement
FA	:	Fly Ash
SP	:	Superplasticizer
I	:	Nominal cement dosage, 400kg/m^3
II	:	Nominal cement dosage, 300kg/m^3
Sample for IC – 15:Nominal cement dosage, 400kg/m^3 and Fly Ash content, 15%		